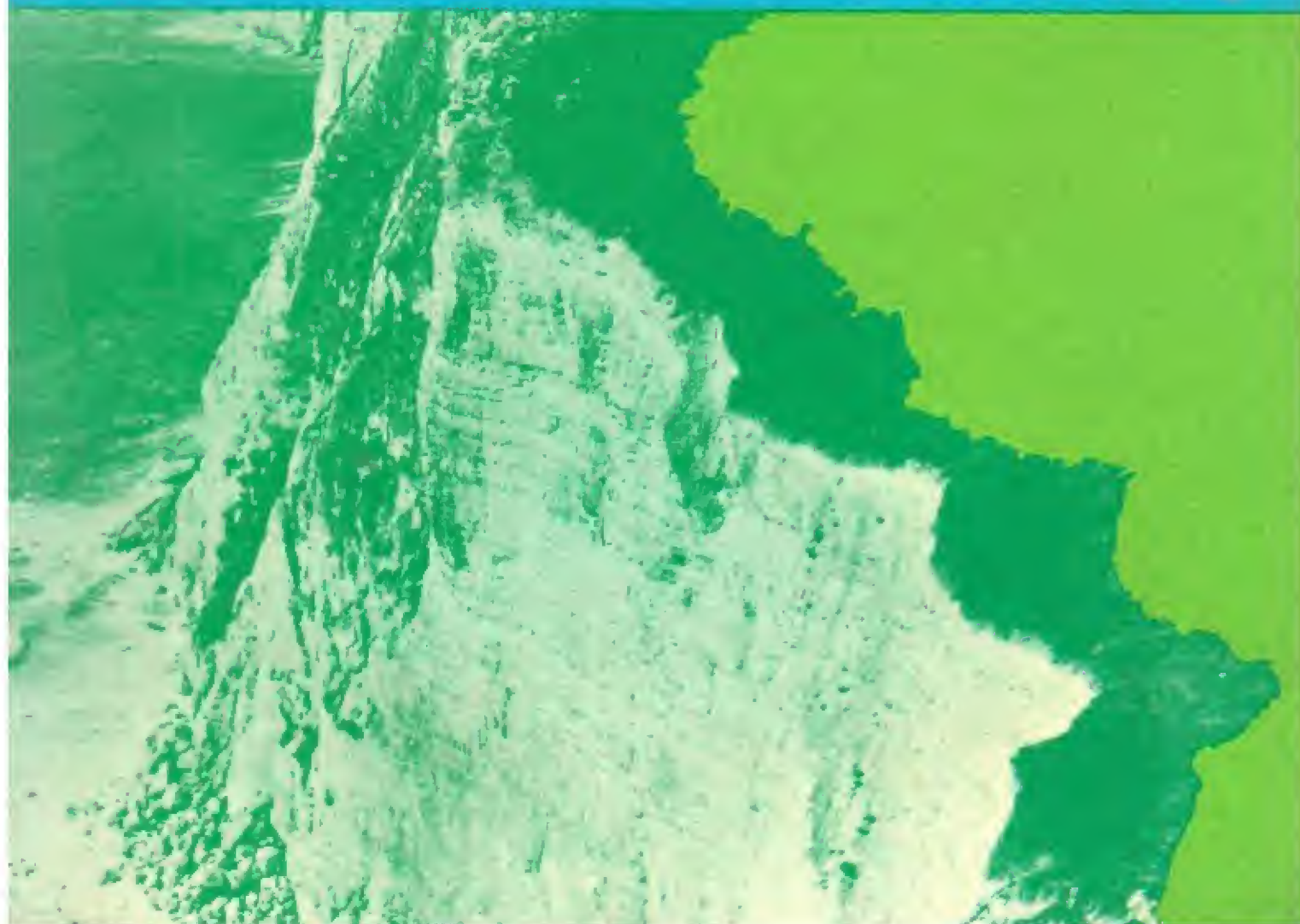


Chemistry Background Book



# Dissolving





*'Almost all chemical processes which occur in nature, whether in animal or vegetable organisms, or in the non-living surface of the Earth, and also those processes which are carried out in the laboratory, take place between substances in solutions.'*

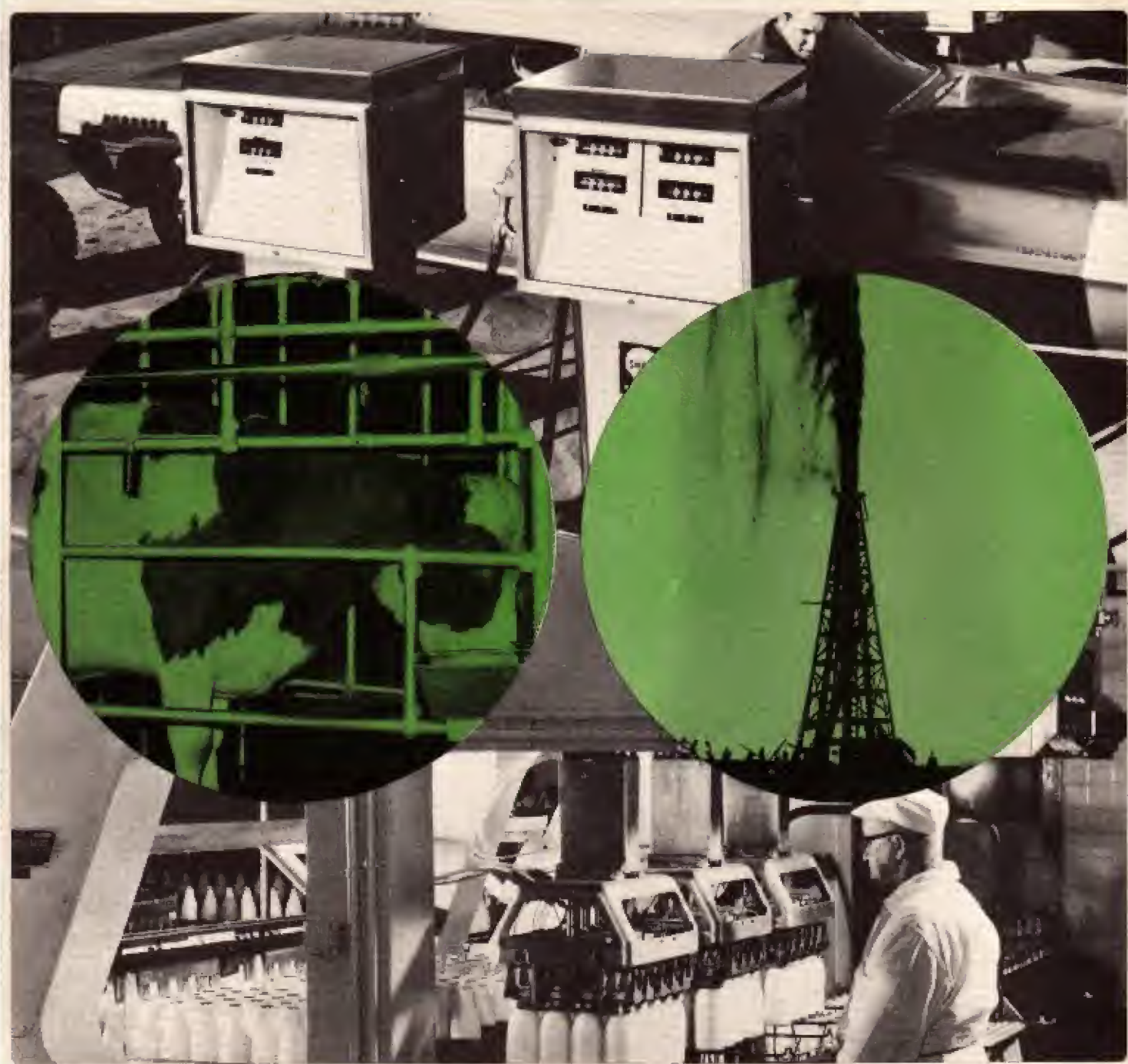
Wilhelm Ostwald



*Shell, I.C.I., Express Dairies,  
Unilever, Sidney Press Ltd.,  
Bedford, Vickers Limited.*

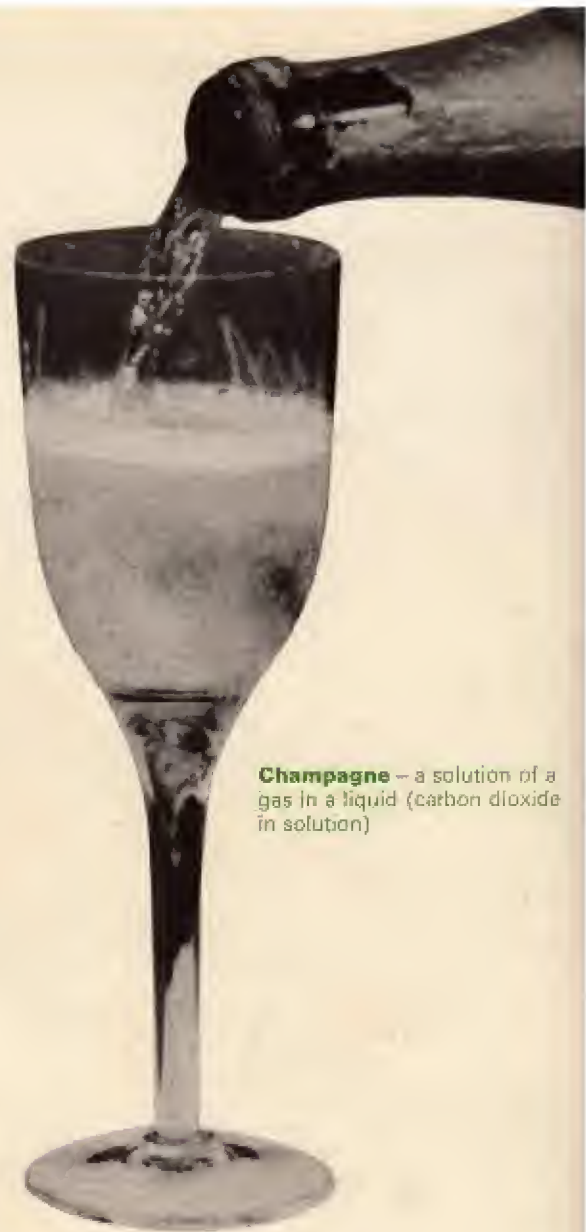






# *what happens when a substance dissolves?*

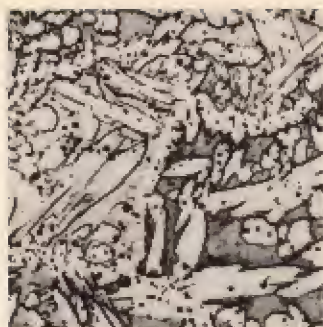
We generally think of solutions in terms of a solid dissolved in a liquid. Although this is the commonest kind of solution, it is only one of several, as the following examples show:



**Champagne** — a solution of a gas in a liquid (carbon dioxide in solution)

**air** — a solution of gases (oxygen, nitrogen, water vapour, carbon dioxide and the inert gases)





**brass** – a solution of a solid in a solid (zinc in copper)

**gasoline** – a solution of liquids (liquid hydrocarbons such as octane, nonane, and decane). Shell.



*If you stir a spoonful of salt in a beaker of water, the salt crystals break down and mix with the water: the salt (called the solute) is said to have dissolved in the water (called the solvent) to form a solution. This dissolving of one substance in another is so familiar that we pass it over without thought. In fact, dissolving poses a number of interesting chemical problems, some of which we shall look at in this book.*

When salt is stirred in water, although the salt apparently disappears, we know that it is still there because we can taste it. Evidently the salt crystals break up into small particles, which are dispersed in the water. They must be very small indeed because they pass through a filter paper and cannot be seen even under the highest powered microscopes.

A clearer picture of what happens in dissolving can be gained by putting a strongly-coloured substance – for example, potassium permanganate – into a beaker of water. At first the colour lies at the bottom of the beaker, concentrated round the permanganate crystals. But it slowly spreads through the water, probably because of the motion of the water molecules. In about three days the water becomes uniformly purple.

No particles are visible, but the purple colour shows they must be there. In fact, it is the permanganate ion ( $\text{MnO}_4^-$ ) which is responsible for the colour; we can show that ions are formed when potassium permanganate dissolves by testing to see whether the solution is a conductor of electricity; the conductivity is much higher than that of pure water. But substances dissolving in water do not always give ions. Dissolving sugar in water does not affect the electrical conductivity: the sugar crystals break down not into electrically charged ions but into electrically neutral molecules.

Dissolving, then, consists of the mingling of ions, atoms, or molecules of one substance with the ions, atoms, or molecules of another. The solute can usually be separated from the solvent by a simple process – for example, by evaporating the solvent or, with a solution of one liquid in another, by fractional distillation. For this reason what happens when, say, a lump of zinc is put in sulphuric acid cannot be regarded as dissolving. When the excess acid is evaporated, it is zinc sulphate and not zinc that is recovered.





## *the part played by the solvent*

When one substance dissolves in another, we tend either to forget the solvent altogether or to regard it simply as an inert medium in which particles of the solute are dispersed. But, for dissolving to occur, there must be some attraction between the particles of the solvent and those of the solute. If the solute is crystalline, this attraction must be sufficiently strong to overcome the attractive forces that hold the particles in the crystal lattice. Common salt will dissolve in water but not in toluene. Conversely crystals of naphthalene will dissolve in toluene but not in water.

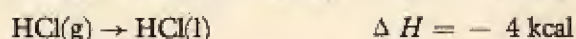
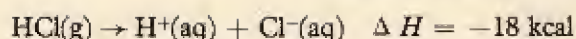
There is no hard and fast rule about which solvent will dissolve a particular solute, but there are some rules of thumb. Water is a good solvent for many ionic compounds. Others are liquid ammonia (b.p.  $-33.4^{\circ}\text{C}$ ), liquid sulphur dioxide (b.p.  $-10.2^{\circ}\text{C}$ ), and liquid hydrogen fluoride (b.p.  $19.54^{\circ}\text{C}$ ). But all these vaporize at very low temperatures. Carbon tetrachloride and benzene are good solvents for carbon compounds. Alcohol and acetone dissolve both ionic and carbon compounds. Gases are completely soluble in each other, presumably because their molecules are widely separated. Liquids vary. Water and alcohol are completely soluble in each other. Water and ether are partially soluble in each other: 5.8 grams of ether will dissolve in 100 grams of water and 4.12 grams of water will dissolve in 100 grams of ether. Water and benzene do not mix to any extent.

Very often it is the solvent which determines whether ions or molecules of the solute will pass into solution. For example, if hydrogen chloride gas is dissolved in water, a great deal of heat is given out (18 kcal per mole)—more than can be accounted for by the latent heat of condensation of hydrogen chloride (4 kcal per mole).

If oxygen were not soluble in water, fish, water plants, and other organisms that live in water, could not survive.  
*Lawrence Barking Photo*  
Reprinted



Blood is one of the main solvents for carrying the reactants (oxygen, sugar, etc.) to the body cells. Here a woman is giving blood which will be given to a patient.



The solution is strongly acidic (suggesting the presence of hydrogen ions), and it conducts electricity much better than pure water. Evidently the hydrogen chloride has ionized on dissolving to form hydrogen ions and chloride ions. If, however, hydrogen chloride gas is dissolved in toluene, there is only a small heat change, the solution is not acidic and will not conduct electricity. Evidently the hydrogen chloride is present in the solution in the form of molecules.

All this adds up to the fact that dissolving is a two-way process involving the solvent as well as the solute, and that the solvent plays a critical part in deciding the nature of the solution.

#### **some common solvents**

Solvents with water-like properties: suitable for dissolving most inorganic substances

**liquid hydrogen cyanide**  
**water**  
**liquid ammonia**  
**hydrazine**  
**liquid hydrogen fluoride**  
**liquid sulphur dioxide**  
**liquid hydrogen sulphide**  
**hydroxylamine**  
**anhydrous nitric acid**  
**anhydrous sulphuric acid**

Solvents with oil-like properties: suitable for dissolving most organic substances

**ether**  
**esters**  
**carbon tetrachloride**  
**pentane**  
**benzene**  
**toluene**  
**trichloroethylene**  
**sulpholane**  
**pyridine**

Solvents with both water-like and oil-like properties: suitable for dissolving both inorganic and organic substances

**acetone**  
**methanol**  
**ethanol**  
**acetic acid**  
**liquid formaldehyde**  
**liquid ethylamine**  
**phenol**  
**carbon disulphide**

Apparatus for finding out whether a solution conducts electricity.





# *saturation*

On adding a solute to a solvent, there often comes a point where no more solute will dissolve. The solution is said to be *saturated*. In the first instance, the weight of solute that will dissolve in a given quantity of solvent depends on the chemical nature of both solute and solvent. Sodium chloride, for example, is very much more soluble in water than is silver chloride. In a saturated solution of sodium chloride in water (at 15°C) there are 35.5 grams of sodium chloride to every 100 grams of water – about one sodium ion and one chloride ion to every ten molecules of water. In a saturated solution of silver chloride in water (at 15°C) there are only 0.00015 grams of silver chloride to every 100 grams of water – in other words, only about one silver ion and one chloride ion to every two million molecules of water. In pure liquid ammonia, sodium chloride is much less soluble than it is in water – only about 3 grams of it can be dissolved in 100 grams of ammonia.

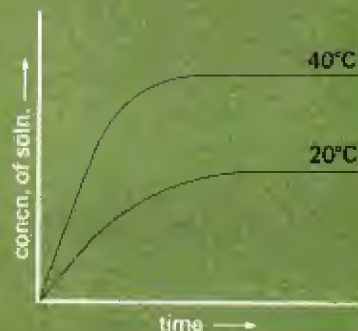
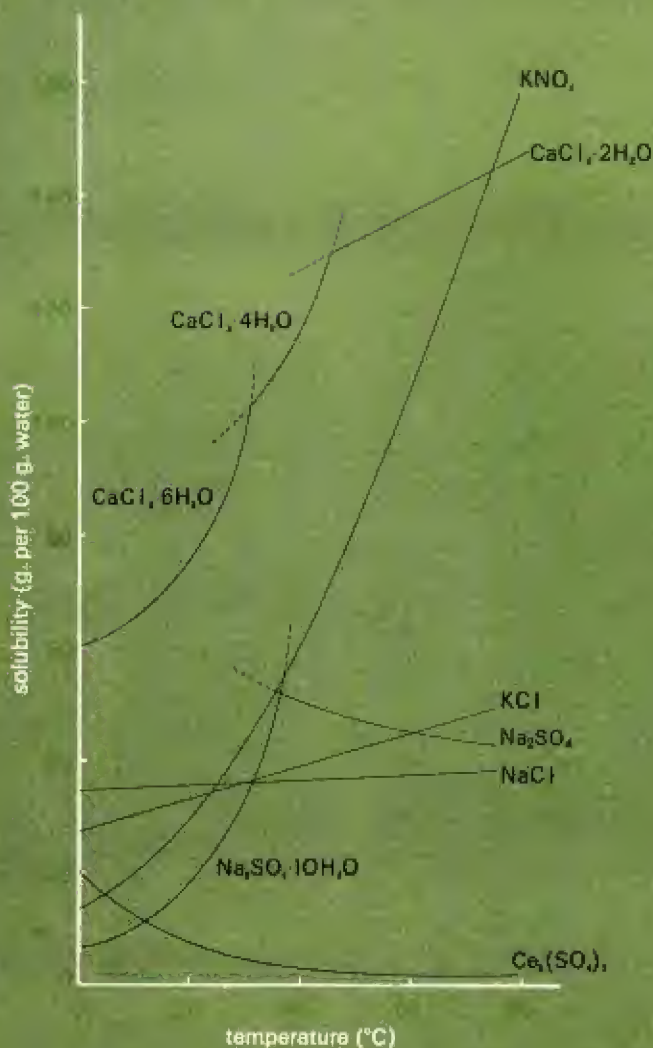
The amount of solute that will dissolve in a solvent may also be influenced by temperature and pressure. Generally, the higher the temperature of a liquid solvent, the greater the quantity of solid solute that will dissolve. But there are some solid substances which are exceptions to this, as the solubility curves on the next page show. Why then, you may ask, do we invariably heat substances to make them dissolve? The answer is that heating them makes them dissolve faster, but that the rate of dissolving has little to do with actual solubility. Gases are more soluble in cool liquids than in hot. For example, at 760 mm pressure, 0.2774 grams of carbon dioxide will dissolve in 100 grams of water at 5°C but less than half as much at 25°C. Moreover, the higher the pressure of the gas, the more gas will dissolve.



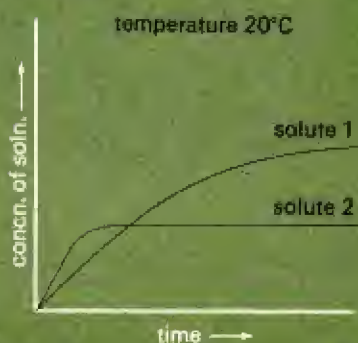


When a saturated solution is cooled, usually some of the solute is precipitated — because solubility usually decreases with a fall in temperature. Sometimes, however, the solute remains in solution and a *supersaturated* solution is formed. To form a precipitate, the solute needs 'seeding' particles on which to grow, and a few small crystals put into the supersaturated solution will cause the solute to crystallize. Here a large crystal is being grown from a small seed crystal in a saturated solution.

The solubility curves of various substances in water showing the effect of temperature on the extent to which a substance dissolves. Usually, increase in temperature results in increase in solubility but, as you can see from the curve for cerium sulphate,  $\text{Ce}_2(\text{SO}_4)_3$ , not always.



Rate of dissolving should not be confused with solubility. In this graph, solute 2 dissolves faster than solute 1 but is less soluble.



# *solutions in the laboratory*

Apparatus used to prepare solutions of known concentration – the solute is weighed in a *balance* and is put in the *measuring flask* where it is made up to the mark with the solvent to give a solution of known concentration.

Solutions are bulky. Therefore solids are usually left in the chemical store room, and solutions are prepared as required.





In the laboratory we are concerned chiefly with investigating reactions between substances. Many important substances are solid at room temperature, but few of them react satisfactorily in a solid form, if only because it is difficult to mix solid substances so that the reacting particles are in intimate contact. This is why most of the reagents in the laboratory are made up as solutions: in this form the reacting particles can be most conveniently brought in contact with each other. Furthermore, in solution the temperature of the reaction can be more easily controlled. To quote the great German chemist Wilhelm Ostwald: 'Almost all the chemical processes which occur in nature, whether in animal or vegetable organisms, or in the non-living surface of the Earth, and also those processes which are carried out in the laboratory, take place between substances in solutions.'

We often want to know the quantities of substances that react. Therefore we have to know the concentrations of the solutions: how much solute in how much solvent. The concentration of a solution is generally expressed in terms of weight of solute (either grams or gram formulae) in volumes of solvent (litres). The solute is carefully weighed and dissolved in a measured volume of solvent: the concentration is then expressed in grams (gram formulae) per litre. For example, if 5 grams of common salt are dissolved in 100 cm<sup>3</sup> of water, the concentration is 50 grams (or 0.85 gram formulae) of common salt per litre. Using a solution of known concentration (for example, a base), the strength of another solution whose concentration is unknown (for example, an acid) can often be determined by measuring the volume of it needed to neutralize a measured volume of base.

Another important use for solvents in the laboratory is in the separation of one substance from a mixture of others. This process is called solvent extraction. You may have used it to separate a mixture of salt and sand. Solvent extraction is also used to purify substances.

Apparatus used for measuring volumes of solutions — pipettes give a fixed volume and burettes for running out a measured quantity.



Solvent extraction — for example, to purify phenol (carbolic acid), it is shaken in a separating funnel with equal parts of ether and water. Ether and water are only slightly soluble in each other and form separate layers with the ether on top of the water. The phenol (which is very soluble in ether but hardly at all in water) dissolves in the ether layer and such impurities as sodium chloride and sulphite (which are soluble in water but not in ether) dissolve in the water layer. The water is run off from the separating funnel, and the pure phenol is then recovered by distilling off the ether.



# *solvents in industry*

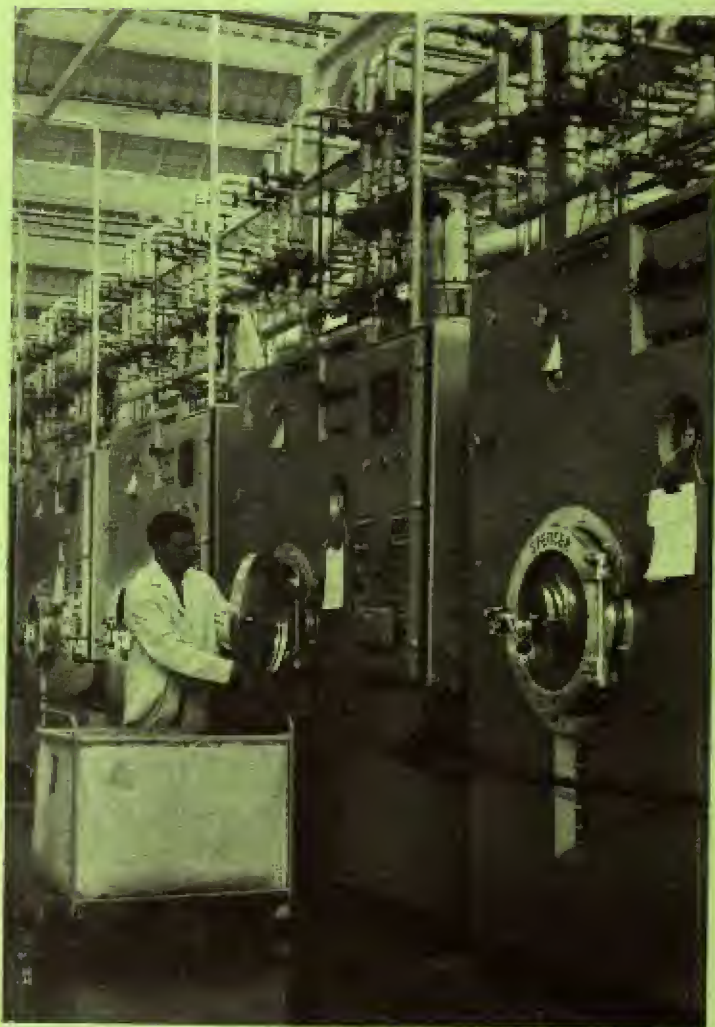
Solvents are used in the industrial manufacture of chemicals for the same reason as they are used in the laboratory – to provide a convenient medium in which substances can react. But in industry, of course, much larger quantities of solvent are involved. Solvent extraction is also often used to separate chemical products and many of the products are dispensed in the form of solutions. This is true for example, of paints, some farm chemicals, and many medicines.

In the long-established inorganic chemicals industry, water has always been by far the most important solvent; it is abundant and cheap, and it dissolves a wide range of inorganic substances. In the organic chemicals industry, which has grown up during the past fifty years and which manufactures such products as plastics and detergents, it is organic solvents which are mainly used. Producing them is one of the industry's biggest jobs.

An important class of organic solvents is based on hydrocarbons, most of which are produced from the fractional distillation of petroleum. Paraffin is fairly typical of this class of solvent. Among the uses of hydrocarbon solvents is the extraction of oils from such seeds as groundnut, coconut, palm kernel, and cotton seed; the plant oils, in turn, are used in the manufacture of margarine, soap, paints, printing inks and a host of other products, and the solvents are recovered for further use. Hydrocarbons tend to catch fire very easily. In applications of solvents where there is a risk of fire, as in dry-cleaning, chlorinated hydrocarbons (e.g. perchloroethylene) are more generally used.

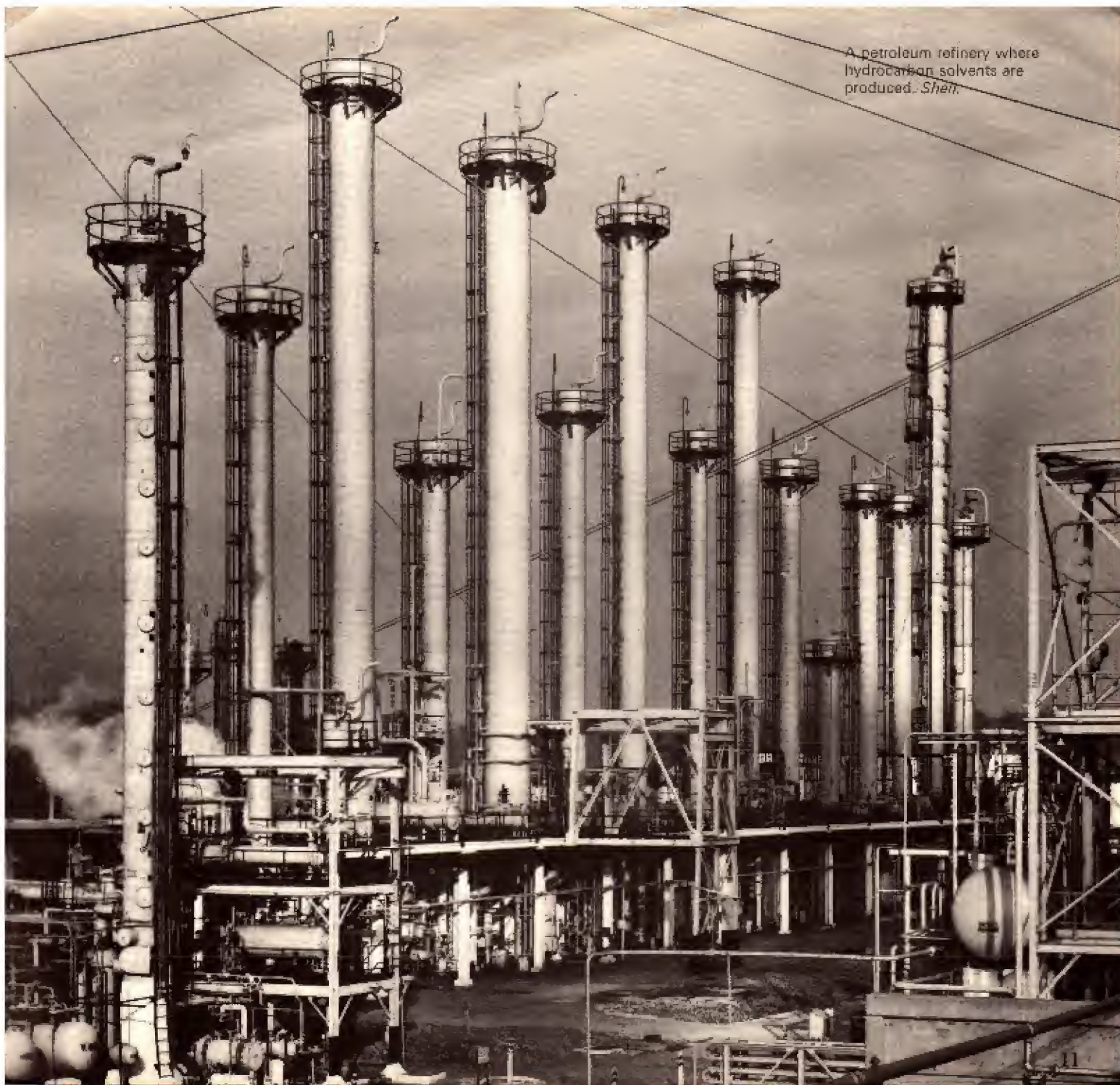
Other organic solvents include alcohols, ketones, esters, and ethers. These can dissolve both organic and inorganic substances and are used in the manufacture of a variety of products – dyestuffs, perfumes, plastics, paints, and glues.

Solvents are used in dry cleaning to remove substances which adhere to clothing.  
*National Federation of Dyers and Cleaners.*





A petroleum refinery where  
hydrocarbon solvents are  
produced. *Shell.*





Some solvent applications :



Photographic developers.  
*Courtesy Kodak Limited.*



Glues are made from bones  
from which fat is removed by  
dissolving it. *John Knight Ltd.*



Printer's ink.





Paints: Shell.



Soap solution plays an important part in detergency.  
John Knight Ltd



Antibiotics are one of many kinds of medicine prepared in solution for injections. G/axo.

### Questions

1. Is water a suitable solvent for sodium? If not, what solvent would you suggest?
2. What is the effect of temperature on the solubility of sodium sulphate in water?
3. Why do fish in aquaria die more often in summer than in winter?
4. In a mixture of ether and water, why does the ether form a layer on top of the water? What does it mean that the water is partially soluble in the ether and the ether is partially soluble in the water?
5. How would you find out whether the particles of solute in a solution were ions or molecules?
6. What is the concentration in moles per litre of a solution in which 7.9 grams of potassium permanganate ( $\text{KMnO}_4$ ) are dissolved in 100  $\text{cm}^3$  of water.
7. Why do you think heat is given out when hydrogen chloride dissolves in water?
8. The solubility of potassium iodide in 100 grams of water is: 127.5 grams at 0°C, 140 grams at 15°C and 208 grams at 100°C. The solubility of sodium nitrate in 100 grams of water is: 73 grams at 0°C, 85 grams at 15°C, and 178 grams at 100°C. Draw the solubility curves for these two substances.

**Chemette Background Books**

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Published by the National Foundation for Longevity Research, 1999

Longevity Research Ltd, 48, St. Andrew's Street, London W1A 1AA

Printed by Longevity Research, Whitton, England

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Made and printed in Great Britain by W. R. Chiswick Limited

08804725

